FAST ALGORITHM FOR 3D RECONSTRUCTION OF ANATOMICAL SURFACES FROM A SET OF CONTOURS OF RADIAL BONE

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Anatomical ultrasound (B-Mode ultrasound) is an essential diagnosing tool in medical practice, especially in pediatrics, cardiology and emergency, due to its high availability, absence of any risk both for patients and medical staff, compact size as well as low costs of examinations. The area of ultrasound applications can be easily extended utilizing the fact that this imaging technique has a relative high time resolution comparing with other medical image modalities. It allows to create real-time diagnosing tools in two, three and even in four dimensions. Musculoskeletal ultrasound is successfully applied for diagnosing injured extremities, as the most frequent trauma in children and adults [5]. Today, the high-end systems are able not only to to detect fractures of long bones as reposition of their fragments but, under special conditions, to help recognizing cracks and deformation of bone surfaces (cortical bones) [8] as well. However, the conventional clinical systems provide only manual approach called freehand ultrasound examinations [7]. A linear transducer (ultrasound head) is usually placed on the patient's skin using gel or over a gel pillow [2]. To acquire one or more sonograms (ultrasonic images) a diagnosing physician tries to find an optimal position and orientation of the transducer relative to the patient's anatomy. Then he or she applies some forces on the ultrasound head in the direction of the patient to avoid attenuation of ultrasound waves in air. The examination of musculoskeletal structures can be carried out usually up to 10–15 cm of depth, depending on the transducer model, selected working wave frequency and quantity of patient's fat in the examination area. This approach has many serious drawbacks for the required diagnosing. Firstly, the examination produces additional pain for injured patients. Secondly, the procedure is very time-consuming. The diagnosing strongly depends on sonographic skills of the operator and is practically restricted for dimensions higher than two. More complex ultrasound scanners that can work in higher dimensions in semi-automatic or automatic modes are commercially available for acquisition of patient anatomy in gynaecology, echocardiography, endocrinology, etc. [1, 4]. They use either special (usually mechanical) transducers or linear transducers coupled with optical, magnetic or mechanical tracking systems. However, the application of similar scanners for examinations of long bones is not a simple task, due to a high variability of the bone anatomy, scattering and total reflection of ultrasound waves from bone surfaces. Developing new scanning principles, approaches to the rapid and accurate processing of the acquired data for analysing injured extremities remain being the challenging tasks, which are especially important for diagnosing injures in children, who are limited in their ability to remain immobile during the scanning time.

In this work we aim at a possible solution of the aforementioned problems for the task of diagnosing injures of long bones. The following results were obtained. Firstly, we created a software simulator of automated ultrasound-based 3D scanner UFASS (Ultrasound-based Fracture Analysis Scanning System, an improved robotized version of the scanner patented in [6]), which is able to acquire a series of realistic ultrasonic images of the long bones' cortical surfaces. Contours are represented by a reference 3D volumetric model of the human limb, obtained using Computed Tomography (CT). The proposed simulator is a virtual device intended for positioning and orienting of the virtual transducers in automatic mode relatively to the scanned 3D object (human limb) and image acquisition utilizing a cross-section of the scanned object and predefined physical properties of the ultrasound. The simulator allows to carry out experiments with realistic results without significant expenses of human and material resources. Secondly, we designed and implemented an efficient algorithm for 3D reconstruction of the anatomical surface of the radial bone using a set of mechanically tracked 2D sonograms. The algorithm includes the following ideas: tiling original data on a set of patches, building a space subdivision inside each patch (interpolating contours lying between pair of neighboring original contours), building a triangulation of each patch and stitching together the resulted surface patches into one mesh. The implementation of the algorithm utilizes kd-trees for the sufficient processing speed. The proposed approach works effectively on irregular, sparse and noisy data, obtained by the software simulator of automated ultrasound-based 3D scanner UFASS.

A series of experiments showed that our algorithm can successfully reconstruct surfaces from anatomical structures with relatively simple geometry (e.g. body of the radial bone) as well as surfaces from objects with more complex geometrical structure and higher curvature (e.g. metaphysis and epiphysis of distal radius), which could not be effectively handled by the prior algorithms [3]. The proposed algorithm reconstructs surfaces with relatively high accuracy, which was confirmed by the quantitative estimation of the root mean square (RMS) of the distances between points of the resulted mesh and points of the reference mesh, obtained from the CT-image of the same bone by the marching cubes algorithm, and the RMS of the distances between points of the not smoothed resulted mesh and the points of the smoothed one. The reconstructed surface correctly interpolates the initial data and demonstrates an appropriate smoothness. It is worth to note that the algorithm builds "almost" regular triangulation of the surface in the sense that almost all triangles have the same dimensions. Moreover, it was experimentally showed that due to the inherently smooth geometry of the radial bone it is possible to emphasize bone areas with possible fractures by calculating local distances from the not smoothed reconstructed surface to the smoothed reconstructed surface. And this potentially can speed up the process of detecting fractures in traumatology. For the visual perception of the experiments we implemented a graphical representation of the results of comparing two meshes, where distances between corresponding points of compared meshes were mapped over a color space and used for visualization of the mesh reconstruction accuracy and locating fractures of the bone.

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